

## MULTISTAGE GEAR PUMP

### BACKGROUND OF THE INVENTION

5 The present invention relates to a multistage gear pump that pressurizes suctioned fluid with gear trains to discharge the pressurized fluid.

Generally, there is a multistage gear pump that pressurizes fluid with gear trains (e.g. Japanese Unexamined Patent Publication No. 2001-140770).

10 FIG. 7 is a longitudinal cross-sectional view of a multistage gear pump 81 (hereinafter referred to as a pump) disclosed in Japanese Unexamined Patent Publication No. 2001-140770. The pump 81 includes a first-stage rotary gear 84 having a pair of gears 82 and 83 and a second-stage rotary gear 87 having a pair of gears 85 and 86. The rotary gears 84 and 87 are arranged in adjacent to each 15 other in an axial direction. The gears 82 and 85 are supported by a drive shaft 88 while the gears 83 and 86 are supported by a driven shaft 89.

In the pump 81, when the drive shaft 88 rotates, the gears 82 and 85 rotate, and the gears 83 and 86 respectively rotate to follow the gears 82 and 85.

20 At the time, the pump 81 sucks liquid, and the sucked liquid flows to the first-stage rotary gear 84 and is pressurized. The pressurized liquid flows to the second-stage rotary gear 87 through a passage 90 that interconnects the

first-stage rotary gear 84 with the second-stage rotary gear 87. The pressurized liquid is further pressurized at the rotary gear 87 and is discharged at a predetermined high-pressure state.

5        For example, it is assumed that dimethylether (DME) is utilized as the liquid. Since the DME easily leaks due to the low viscosity, the DME leaks out from gear portions of the rotary gears 84 and 87 in an operating state of the pump 81. Therefore, an amount of the pressurized DME sent from the first-stage rotary gear 84 to the second-stage rotary gear 87, that is, an actual amount of the DME 10 discharged from the first-stage rotary gear 84 is smaller than a discharge capacity (a theoretical value) of the first-stage rotary gear 84 due to the above leakage.

Therefore, when the facewidth of the rotary gear 84 is equal to that of the rotary gear 87 as disclosed in Japanese Unexamined Patent Publication No. 15 2001-140770, that is, when the discharge capacity of the first-stage rotary gear 84 is equal to that of the second-stage rotary gear 87, the actual discharge capacity of the first-stage rotary gear 84 is insufficient for the discharge capacity of the second-stage rotary gear 87. Since the DME has the nature of a relatively 20 high vapor pressure (a relatively high volatility), the pressure of the DME falls below the vapor pressure and vaporizes. In the result, the DME cannot be pressurized to a predetermined pressure.

## SUMMARY OF THE INVENTION

The present invention provides a multistage gear pump that can ensure pressurization characteristics for fluid.

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In accordance with the present invention, a multistage gear pump for pressurizing fluid includes a housing, a drive shaft and a gear assembly. The drive shaft is rotatably supported in the housing. The gear assembly is disposed in the housing. The gear assembly includes at least first and second gear trains.

10 Each train has a pair of drive and driven gears that are engaged with each other. The drive gear is provided on the drive shaft and followed by the driven gear. The first gear train and the second gear train are arranged so that fluid sequentially passes therethrough as the drive shaft rotates. A theoretical discharge capacity of the first gear train is larger than that of the second gear train.

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The present invention also provides a multistage gear pump for pressurizing fluid. The multistage gear pump includes a housing, a drive shaft, a driven shaft and a gear assembly. The drive shaft is rotatably supported in the housing. The driven shaft is rotatably supported in the housing. The gear assembly is disposed in the housing. The gear assembly includes at least first and second gear trains. Each train has a pair of drive and driven gears that are engaged with each other. The drive gear is provided on the drive shaft and

followed by the driven gear. The first gear train and the second gear train are arranged so that fluid sequentially passes therethrough as the drive shaft rotates. One of the driven gears is formed with the driven shaft so as to rotate integrally with the driven shaft. The rest of the driven gears are assembled to the driven shaft so as to rotate relative to the driven shaft.

#### 5 BRIEF DESCRIPTION OF THE DRAWINGS

The features of the present invention that are believed to be novel are set forth with particularity in the appended claims. The invention together with objects and advantages thereof, may best be understood by reference to the following description of the presently preferred embodiments together with the accompanying drawings in which:

15 FIG. 1A is a longitudinal cross-sectional view of a three-stage gear pump according to a first preferred embodiment;

FIG. 1B is a partially enlarged longitudinal cross-sectional view of the three-stage gear pump according to the first preferred embodiment;

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FIG. 2 is a cross-sectional view of the three-stage gear pump taken along the line II - II in FIG. 1A;

FIG. 3 is a cross-sectional view of the three-stage gear pump taken along the line III - III in FIG. 1A;

5 FIG. 4 is a schematic view of a fuel supply system according to the first preferred embodiment;

10 FIG. 5 is a partially enlarged longitudinal cross-sectional view of the three-stage gear pump around an O-ring according to the first preferred embodiment;

FIG. 6 is a longitudinal cross-sectional view of a two-stage gear pump according to a second preferred embodiment; and

15 FIG. 7 is a longitudinal cross-sectional view of a multistage gear pump according to a prior art.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

20 Hereinafter, first and second preferred embodiments according to the present invention will be described. The present invention is applied to a multistage gear pump for use in a fuel supply system for supplying fuel

(dimethylether) to an engine as a drive source for a vehicle.

Now, the first preferred embodiment will be described. FIG. 4 is a schematic view of a fuel supply system. Dimethylether (DME) as fluid is stored in 5 a tank 2 that is connected to a multistage gear pump 1 (a three-stage gear pump in the present preferred embodiment and referred to as a pump hereinafter) at the input side of the pump 1 through a suction pipe 3. An injection pump 5 is connected to the pump 1 at the output side of the pump 1 through a discharge pipe 4. An engine 6 is connected to the injection pump 5 at the output side of the 10 injection pump 5. The pressurized DME is sent from the pump 1 to the injection pump 5, which supplies the DME having a high pressure into the engine 6.

FIG. 1A is a longitudinal cross-sectional view of the pump 1. When the pump 1 is installed in a vehicle, the left and right sides of the pump 1 in FIG. 1A 15 respectively correspond to the upper and the lower sides of the pump 1. The pump 1 includes a casing 7 and a cover 9. The casing 7 has a cylindrical shape with a bottom. The cover 9 is secured to the casing 7 through a plurality of bolts 8. The casing 7 and the cover 9 constitute a housing of the pump 1. A motor 10 as a drive source and a gear assembly 11 are accommodated in the casing 7. The 20 motor 10 is secured to the inner surface of the cover 9. The gear assembly 11 is fixed to the motor 10.

The motor 10 includes a motor housing 10a, a stator 10b and a rotor 10c. The stator 10b has a coil that is arranged along the inner circumferential surface of the motor housing 10a. The rotor 10c includes an iron core that is arranged so as to be surrounded by the stator 10b. The rotor 10c is integrally and rotatably secured to a drive shaft 12. A bearing 13 is arranged at the motor housing 10a on the upper side, and a bearing 14 is arranged in a bottom plate 22. Both ends of the drive shaft 12 are respectively supported by the bearings 13 and 14. Namely, the drive shaft 12 is supported in the housing rotatably. The coil of the stator 10b is connected to a terminal 15. When an external device supplies electric current to the coil through the terminal 15, the drive shaft 12 rotates due to the action of electromagnetic induction between the coil of the stator 10b and the iron core of the rotor 10c.

As shown in FIGs. 1A and 1B, the gear assembly 11 includes a base block 16, a connecting plate 17, a side plate 18, a connecting plate 19, a side plate 20, a connecting plate 21 and the bottom plate 22 in order from a side of the motor 10. The drive shaft 12 extends through the base block 16 and these plates 17 through 22. In this state, the base block 16 and these plates 17 through 22 are integrally fixed to each other by threading a plurality of bolts 23 (shown in FIGs. 2 and 3) thereinto. A plurality of bolts 24 is threaded into the motor housing 10a through a flange 16a of the base block 16. Therefore, the gear assembly 11 is fixed to the motor 10.

The drive shaft 12 extends through the base 16 and the plates 17 through 22 that constitute the gear assembly 11, and the lower end of the drive shaft 12 is supported by the bottom plate 22 through the bearing 14. A groove 12a is formed on the outer circumferential surface of the drive shaft 12 at the lower side. A key 25 having a rectangular solid shape is fitted in the groove 12a.

Three gears 26 through 28 are provided on the drive shaft 12 in order from the lower side along an axial direction of the drive shaft 12. Gear tooth 26a through 28a are respectively formed on the outer circumferential surfaces of the gears 26 through 28. Key seats 26b through 28b are respectively formed on the inner circumferential surfaces of the gears 26 through 28. The key 25 is locked in the key seats 26b through 28b. Therefore, the gears 26 through 28 rotate integrally with the drive shaft 12. The same material is used for the side plates 18 and 20. Incidentally, the gears 26 through 28 are drive gear.

The gear assembly 11 accommodates a driven shaft 29 that is parallel to the drive shaft 12. The driven shaft 29 extends through the base 16 and the plates 17 through 22 that constitute the gear assembly 11. The upper end of the driven shaft 29 is supported by the base block 16 through a bearing 30, and the lower end of the driven shaft 29 is supported by the bottom plate 22 through a bearing 31.

Three gears 32 through 34 are provided on the driven shaft 29 in order from the lower side along an axial direction of the driven shaft 29. Gear tooth 32a through 34a are respectively formed on the outer circumferential surfaces of the 5 gears 32 through 34. The gear 32, which is at the lowest side, is formed integrally with the driven shaft 29. On the other hand, the gears 33 and 34 respectively have through holes, and the driven shaft 29 penetrates through the through holes of the gears 33 and 34. Therefore, the gears 33 and 34 are assembled to the driven shaft 29 so as to be rotatable relative to the driven shaft 29. The gears 26 10 and 32 have a same facewidth  $h_1$ , the gears 27 and 33 have a same facewidth  $h_2$ , and the gears 28 and 34 have a same facewidth  $h_3$ . The gears 26 through 28 are respectively engaged with the gears 32 through 34. Incidentally, the gears 32 through 34 are driven gear.

15 A suction connecting portion 35 is connected to the outer circumferential surface of the casing 7. The suction pipe 3 extended from the tank 2 is connected to the suction connecting portion 35. The pump 1 sucks the DME in the tank 2 from a suction port 35a in an operating state of the pump 1. The pump 1 is a series-type pump that pressurizes the sucked DME by passing the sucked DME 20 through a plurality of gear trains. Namely, the pump 1 passes the sucked DME through a first-stage gear train 36 constituted of the gears 26 and 32, a second-stage gear train 37 constituted of the gears 27 and 33 and a third-stage

gear train 38 constituted of the gears 28 and 28 sequentially, thereby pressurizing the sucked DME. As shown in FIG. 2, a discharge connecting portion 39 is connected to the outer circumferential surface of the casing 7. The pump 1 discharges the pressurized DME from a discharge port 39a of the discharge 5 connecting portion 39.

In a relationship between the first-stage gear train 36 and the second-stage gear train 37, the first-stage gear train 36 and the second-stage gear train 37 are respectively considered a low-pressure stage gear train or a first 10 gear train and a high-pressure stage gear train or a second gear train. In a relationship between the second-stage gear train 37 and the third-stage gear train 38, the second-stage gear train 37 and the third-stage gear train 38 are respectively considered a low-pressure stage gear train and a high-pressure stage gear train. The third-stage gear train 38 is the highest-pressure stage gear 15 train whose pressure is the largest among the gear trains 36 through 38.

FIG. 2 is a cross-sectional view of the pump 1 taken along the line II - II in FIG. 1A, and FIG. 3 is a cross-sectional view of the pump 1 taken along the line III - III in FIG. 1A. As shown in FIG. 2, holes 21a and 21b are respectively formed in the 20 connecting plate 21 for accommodating the gears 26 and 32. In the connecting plate 21, slight space regions are provided on forward and backward sides of the place where the gear 26 is engaged with the gear 32, thereby defining

upstream and downstream passages 40 and 41 as a passage for the DME. The upstream passage 40 communicates with the suction port 35a. Similarly, holes and upstream and downstream passages are formed in each of the connected plates 17 and 19.

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The drive shaft 12 is rotated by the drive of the motor 10 in a direction (clockwise) indicated by an arrow A in FIG. 2. The driven shaft 29 is rotated in a direction indicated by an arrow B in FIG. 2 in accordance with the rotation of the drive shaft 12 through the first-stage gear train 36. The DME is drawn into the 10 inside of the pump 1 due to the rotations of the drive shaft 12 and the driven shaft 29, and flows to the first-stage gear train 36 through the suction port 35a and the upstream passage 40. Pump chambers 36a are defined by the adjacent gear tooth 26a of the gear 26 and the inner circumferential surface of the hole 21a. Pump chambers 36b are defined by the adjacent gear tooth 32a of the gear 32 15 and the inner circumferential surface of the hole 21b. The DME that reaches the first-stage gear train 36 is sent toward the downstream passage 41 through the pump chambers 36a and 36b.

As shown in FIG. 3, adjacent holes 20a and 20b are respectively formed 20 in the side plate 20 such that the drive shaft 12 and the driven shaft 29 extend therethrough. The diameter of the hole 20a is set to be larger than that of the drive shaft 12. Therefore, a clearance is formed between the inner circumferential

surface of the hole 20a and the outer circumferential surface of the drive shaft 12.

The diameter of the hole 20b is set to be larger than that of the driven shaft 29.

Therefore, a clearance is formed between the inner circumferential surface of the hole 20b and the outer circumferential surface of the driven shaft 29.

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A communication passage 43 is formed in the side plate 20 and interconnects the downstream passage 41 at the first-stage gear train 36 with an upstream passage 42 at the second-stage gear train 37. The communication passage 43 includes first, second and third passages 43a through 43c. The first passage 43a extends in a radial direction of the pump 1. The second passage 43b extends from the downstream passage 41 at the first-stage gear train 36 in the axial direction and communicates with the first passage 43a. The third passage 43c extends from the upstream passage 42 at the second-stage gear train 37 and communicates with the first passage 43a.

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Pump chambers 37a are defined by the adjacent gear tooth 27a of the gear 27 and the inner circumferential surface of the connecting plate 19. Pump chambers 37b are defined by the adjacent gear tooth 33a of the gear 33 and the inner circumferential surface of the connecting plate 19. The DME that reaches the second-stage gear train 37 is sent to the third-stage gear train 38 through the pump chambers 37a and 37b. Also, pump chambers 38a are defined by the adjacent gear tooth 28a of the gear 28 and the inner circumferential surface of the

connecting plate 17. Pump chambers 38b are defined by the adjacent gear tooth 34a of the gear 34 and the inner circumferential surface of the connecting plate 17. The DME that reaches the third-stage gear train 38 is sent to the discharge port 39a through the pump chambers 38a and 38b.

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As shown in FIG. 1B, O-rings 48a through 48f are respectively arranged in the gear assembly 11 for ensuring sealing between the pump chambers 36a through 38a and 36b through 38b and the interior of the casing 7. The O-rings 48a through 48f are arranged so as to surround the drive shaft 12 and the driven shaft 29. There is an internal chamber 51 around the drive shaft 12 in the gear assembly 11. Seal rings 49a through 49f are respectively arranged in the gear assembly 11 for ensuring sealing between the pump chambers 36a through 38a and the internal chamber 51. The seal rings 49a through 49f are arranged so as to surround the drive shaft 12.

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There is an internal chamber 52 around the driven shaft 29 in the gear assembly 11. Seal rings 50a through 50f are respectively arranged in the gear assembly 11 for ensuring sealing between the pump chambers 36b through 38b and the internal chamber 52. The seal rings 50a through 50f are arranged so as to surround the driven shaft 29. Nitrile rubber is used for the material of the O-rings 48a through 48f. Polytetrafluoroethylene is used as the material of the seal rings 49a through 49f and 50a through 50f.

Sealing state of the seal ring 49a will be described with reference to FIG.

5. The seal rings 49b through 49f and 50a through 50f also behave in the same manner as the seal ring 49a. Since the DME in the pump chamber 36a is  
5 pressurized more than that in the internal chamber 51, the DME flows from the pump chamber 36a into a groove 53 that accommodates the seal ring 49a as shown by an arrow C in FIG. 5. Due to the flow of the DME, the seal ring 49a moves toward the sides of gear 26 and the drive shaft 12 and contacts the side surface of the gear 26 and the undersurface of the groove 53, thereby creating  
10 sealing.

As shown in FIG. 1B, the internal chamber 51 is divided into first, second and third chambers 51a through 51c in order from the lower side of the drive shaft 12 by the gears 26 through 28. The chambers 51a through 51c communicate with  
15 each other through a slight clearance between the key 25 and the groove 12a. A return passage (not shown) is formed in the gear assembly 11 so as to interconnect the third chamber 51c with the suction port 35a.

Since the DME has a low viscosity, the DME (vapor liquid) leaks out  
20 from the pump chambers 36a through 38a into the internal chamber 51 via the seal rings 49a through 49f. When the high-pressure DME leaks out into the internal chamber 51 as mentioned above, the pressure in the internal chamber 51

increases due to the high-pressure DME. Therefore, it is thought that thrust load acts on the drive shaft 12 in the axial direction. However, the leaking DME in the internal chamber 51 is returned to the suction port 35a through the return passage. Therefore, the pressure in the internal chamber 51 is substantially equal

5 to a suction pressure, and the thrust load does not act on the drive shaft 12.

As shown in FIG. 3, sealing members 44 and 45 respectively seals both ends of the communication passage 43. A relief valve 46 as a valve means is provided at the end portion of the first passage 43a at a side of the second

10 passage 43b of the communication passage 43 in the side plate 20. A hole 46b is formed in a valve chamber 46a of the relief valve 46 so as to communicate with the discharge port 39a. The relief valve 46 includes a valve body 46c and an urging spring 46d. The valve body 46c has a spherical shape. The urging spring 46d urges the valve body 46c in a direction in which the relief valve 46 closes.

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Similarly to the side plate 20, a communication passage 47 is formed in the side plate 18 as shown in FIG. 1B. The communication passage 47 interconnects a downstream passage at the second-stage gear train 37 with an upstream passage at the third-stage gear train 38. A relief valve (not shown) is

20 also provided in the side plate 18. A downstream passage (not shown) at the third-stage gear train 38 is formed in the base block 16 and communicates with the discharge connecting portion 39. A flow path includes the suction port 35a, the

upstream passages 40 and 42, the upstream passage at the third-stage gear train 38, the downstream passage 41, the downstream passages at the second and third gear trains 37 and 38, the communication passages 43 and 47, the pump chambers 36a through 38a and 36b through 38b, and discharge port 39a.

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When a pressure of the DME discharged into the communication passage 43 is lower than a predetermined value, the valve body 46c contacts a valve seat 46e due to the spring force of the urging spring 46d to close the relief valve 46. Therefore, substantially all of the DME discharged into the 10 communication passage 43 is sent to the second-stage gear train 37. On the other hand, when the pressure of the DME discharged into the communication passage 43 is larger than the predetermined value, the valve body 46c is pushed away from the valve seat 46e against the urging spring 46d. The DME is directly discharged into the discharge port 39a through the hole 46b by bypassing the 15 second-stage and third-stage gear trains 37 and 38.

As shown in FIG. 1A, a pipe connecting portion 54 is connected to the cover 9. A pipe 55 for leak is extended from the tank 2 and is connected to the pipe connecting portion 54 as shown in FIG. 4. A port 56 for leak is formed in the 20 pipe connecting portion 54 so as to interconnect the internal space of the motor 10 with the outside of the pump 1. A drain hole 57 is formed in the sidewall of the motor housing 10a so as to interconnect the internal space of the motor 10 with a

space that is inside the casing 7 and outside the motor housing 10a.

In the pump 1 that seals a shaft therein, sliding portions of the motor 10 and the gear assembly 11, for example, the gears 26 through 28 and 32 through 5 34, the drive shaft 12 and the driven shaft 29 generate heat. Due to the heat, the DME leaking out from the gear trains 36 through 38 vaporizes. It is thought that the vaporizing DME is stored in the internal space of the motor housing 10a and the space that is inside the casing 7 and outside the motor housing 10a.

10 However, the DME gas in the internal space of the motor housing 10a is returned from the port 56 into the tank 2 through the pipe 55. The DME gas in the space that is inside the casing 7 and outside the motor housing 10a flows into the internal space of the motor housing 10a through the drain hole 57 and is returned from the port 56 into the tank 2 through the pipe 55.

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As shown in FIG. 4, a feedback pipe 58 connects the pipe 55 to the injection pump 5. The redundant DME that is not injected and that remains in the injection pump 5 is returned into the tank 2 through the feedback pipe 58 and the pipe 55.

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As shown in FIG. 1B, a theoretical discharge capacity of the first-stage gear train 36 is determined as D1 in one rotation of the gears 26 and 32. The fluid

leakage is not considered into the theoretical discharge capacity D1 of the first-stage gear train 36. An actual discharge capacity S1 of the first-stage gear train 36 is smaller than the theoretical discharge capacity D1 of the first-stage gear train 36 due to the leakage of the DME, which is caused due to the low viscosity of the DME. Similarly, a theoretical discharge capacity of the second-stage gear train 37 is determined as D2. An actual discharge capacity S2 of the second-stage gear train 37 is smaller than the theoretical discharge capacity D2 of the second-stage gear train 37. Also, a theoretical discharge capacity of the third-stage gear train 38 is determined as D3. An actual discharge capacity S3 of the third-stage gear train 38 is smaller than the theoretical discharge capacity D3 of the third-stage gear train 38.

When the DME is pressurized at the gear trains 36 through 38, the DME leaks out from the gear trains 36 through 38. Therefore, the actual discharge capacities S1 through S3 of the gear trains 36 through 38, that is, actual volumes of the DME discharged from the gear trains 36 through 38 respectively reduce in comparison to the theoretical discharge capacities D1 through D3. In the pump 1 of the present preferred embodiment, the leakage of the DME is suppressed by utilizing the above sealing structure (the O-rings 48a through 48f and the seal rings 49a through 49f and 50a through 50f). Consequently, the actual discharge capacity S1 of the first-stage gear train 36 is determined to be 70 to 80 percentages of the theoretical discharge capacity D1, and the actual discharge

capacity S2 of the second-stage gear train 37 is determined to be 70 to 80 percentages of the theoretical discharge capacity D2.

As mentioned in the above background, when the theoretical discharge capacity D1 of the first-stage gear train 36 is equal to the theoretical discharge capacity D2 of the second-stage gear train 37, the actual discharge capacity S1 of the first-stage gear train 36 is insufficient for the theoretical discharge capacity D2 of the second-stage gear train 37. Therefore, the DME cannot be pressurized to a predetermined pressure. Also, when the theoretical discharge capacity D2 of the second-stage gear train 37 is equal to the theoretical discharge capacity D3 of the third-stage gear train 38, the actual discharge capacity S2 of the second-stage gear train 37 is insufficient for the theoretical discharge capacity D3 of the third-stage gear train 38. Therefore, the DME cannot be pressurized to a predetermined pressure.

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In the present preferred embodiment, the theoretical discharge capacity D2 of the second-stage gear train 37 is set to be smaller than the theoretical discharge capacity D1 of the first-stage gear train 36. Also, the theoretical discharge capacity D3 of the third-stage gear train 38 is set to be smaller than the theoretical discharge capacity D2 of the second-stage gear train 37. Therefore, it is suppressed that the actual discharge capacity S1 of the first-stage gear train 36 is insufficient for the theoretical discharge capacity D2 of the second-stage gear

train 37. Also, it is suppressed that the actual discharge capacity  $S_2$  of the second-stage gear train 37 is insufficient for the theoretical discharge capacity  $D_3$  of the third-stage gear train 38. Therefore, the DME is difficult to vaporize at the second and third gear trains 37 and 38.

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The theoretical discharge capacities  $D_1$  through  $D_3$  of the gear trains 36 through 38 are respectively proportional to the facewidths  $h_1$  through  $h_3$  of the gear trains 36 through 38. The theoretical discharge capacities  $D_1$  through  $D_3$  of the gear trains 36 through 38 are respectively determined by the facewidths  $h_1$  through  $h_3$  of the gear trains 36 through 38. Namely, the facewidth  $h_2$  of the

10 second-stage gear train 37 is set to be smaller than the facewidth  $h_1$  of the first-stage gear train 36, and the facewidth  $h_3$  of the third-stage gear train 38 is set to be smaller than the facewidth  $h_2$  of the second-stage gear train 37.

15 In the relationship between the first-stage gear train 36 and the second-stage gear train 37, the facewidth  $h_2$  of the second-stage gear train 37 as the high-pressure stage gear train is set to be smaller than the facewidth  $h_1$  of the first-stage gear train 36 as the low-pressure stage gear train. Therefore, the theoretical discharge capacity  $D_2$  of the second-stage gear train 37 is set to be 20 smaller than the theoretical discharge capacity  $D_1$  of the first-stage gear train 36. The first and second gear trains 36 and 37 are respectively constituted of the gears 26 and 32 and the gears 27 and 33. Namely, the gears 26, 27, 32 and 33

have the same shapes and the same dimensions with respect to end faces around the gear tooth 26a, 27a, 32a and 33a. Therefore, the shapes and the dimensions of the gear tooth 26a and 32a of the gears 26 and 32 are same as those of the gear tooth 27a and 33a of the gears 27 and 33 except for the 5 facewidths  $h_1$  and  $h_2$ . The relationship between the second and third gear trains 37 and 38 is same.

Meanwhile, assuming that the theoretical discharge capacity  $D_2$  of the second-stage gear train 37 is set to be excessively smaller than the theoretical 10 discharge capacity  $D_1$  of the first-stage gear train 36, an excessive amount of the DME is sent from the first-stage gear train 36 to the second-stage gear train 37. Leak rate of the DME at the second-stage gear train 37 is excessive. Also, assuming that the theoretical discharge capacity  $D_3$  of the third-stage gear train 38 is set to be excessively smaller than the theoretical discharge capacity  $D_2$  of 15 the second-stage gear train 37, leak rate of the DME at the third-stage gear train 38 is similarly excessive.

In the present preferred embodiment, the theoretical discharge capacity  $D_2$  of the second-stage gear train 37 is equal to the actual discharge capacity  $S_1$  20 of the first-stage gear train 36. Also, the theoretical discharge capacity  $D_3$  of the third-stage gear train 38 is equal to the actual discharge capacity  $S_2$  of the second-stage gear train 37. Therefore, the DME is not excessively sent from the

first-stage gear train 36 to the second-stage gear train 37. The leak rate of the DME at the second-stage gear train 37 is not relatively large. Also, the DME is not excessively sent from the second-stage gear train 37 to the third-stage gear train 38, and the leak rate of the DME at the third-stage gear train 38 is not relatively 5 large.

The theoretical discharge capacity D2 of the second-stage gear train 37 is equal to the actual discharge capacity S1 of the first-stage gear train 36. This equal includes a slight tolerance that obtains substantially the same effect. A 10 maximum tolerance of the slight tolerance is 10 percentages of the theoretical discharge capacity D1 of the first-stage gear train 36. To obtain a more advantageous effect, the maximum tolerance is 5 percentages of the theoretical discharge capacity D1 of the first-stage gear train 36. Also, the theoretical discharge capacity D3 of the third-stage gear train 38 is equal to the actual 15 discharge capacity S2 of the second-stage gear train 37. This equal also includes a slight tolerance. A maximum tolerance of the slight tolerance is 10 percentages of the theoretical discharge capacity D2 of the second-stage gear train 37. To obtain the more advantageous effect, the maximum tolerance is 5 percentages of the theoretical discharge capacity D2 of the second-stage gear train 37.

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Therefore, assuming that the actual discharge capacity S1 of the first-stage gear train 36 is 70 percentages of the theoretical discharge capacity

D1 of the first-stage gear train 36, the theoretical discharge capacity D2 of the second-stage gear train 37 is set to be 60 to 80 percentages of the theoretical discharge capacity D1 of the first-stage gear train 36. To obtain the more advantageous effect, the theoretical discharge capacity D2 of the second-stage gear train 37 is set to be 65 to 75 percentages of the theoretical discharge capacity D1 of the first-stage gear train 36. Namely, the facewidth h2 of the second-stage gear train 37 is set to be 60 to 80 percentages of the facewidth h1 of the first-stage gear train 36. To obtain the more advantageous effect, the facewidth h2 of the second-stage gear train 37 is set to be 65 to 75 percentages of the facewidth h1 of the first-stage gear train 36.

Therefore, assuming that the actual discharge capacity S2 of the second-stage gear train 37 is 70 percentages of the theoretical discharge capacity D2 of the second-stage gear train 37, the theoretical discharge capacity D3 of the third-stage gear train 38 is set to be 60 to 80 percentages of the theoretical discharge capacity D2 of the second-stage gear train 37. To obtain the more advantageous effect, the theoretical discharge capacity D3 of the third-stage gear train 38 is set to be 65 to 75 percentages of the theoretical discharge capacity D2 of the second-stage gear train 37. Namely, the facewidth h3 of the third-stage gear train 38 is set to be 60 to 80 percentages of the facewidth h2 of the second-stage gear train 37. To obtain the more advantageous effect, the facewidth h3 of the third-stage gear train 38 is set to be 65 to 75

percentages of the facewidth  $h_2$  of the second-stage gear train 37.

Next, action of the pump 1 as constructed above will be described.

When the motor 10 is energized and the drive shaft 12 rotates, the pump 1 sucks

5 the DME in the tank 2 through the suction pipe 3. The sucked DME is sent to the suction side of the first-stage gear train 36 and is pressurized by flowing through the pump chambers 36a and 36b at the first-stage gear train 36. At the time, a predetermined amount of the DME leaks out from the pump chambers 36a and 10 36b to the outside of the pump chambers 36a and 36b. The DME having the actual volume, which is decreased by the predetermined amount, corresponding to the actual discharge capacity  $S_1$  flows to the second-stage gear train 37 through the communication passage 43.

The DME is pressurized further by flowing through the pump chambers

15 37a and 37b at the second-stage gear train 37. At the time, a predetermined amount of the DME leaks out from the pump chambers 37a and 37b to the outside of the pump chambers 37a and 37b. The DME having the actual volume, which is decreased by the predetermined amount, corresponding to the actual discharge capacity  $S_2$  flows to the third-stage gear train 38 through the 20 communication passage 47. The DME is pressurized further by flowing through the pump chambers 38a and 38b. A predetermined amount of the DME leaks out from the pump chambers 38a and 38b to the outside of the pump chambers 38a

and 38b. The DME having the actual volume, which is decreased by the predetermined amount, corresponding to the actual discharge capacity S3 is supplied into the injection pump 5 through the discharge port 39a and the discharge pipe 4.

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Following advantageous effects are obtained in the present preferred embodiment.

(1-1) In the present preferred embodiment, the theoretical discharge capacity D2 of the second-stage gear train 37 is set to be smaller than the theoretical discharge capacity D1 of the first-stage gear train 36. Also, the theoretical discharge capacity D3 of the third-stage gear train 38 is set to be smaller than the theoretical discharge capacity D2 of the second-stage gear train 37. Therefore, it is suppressed that the actual discharge capacity S1 of the first-stage gear train 36 is insufficient for the theoretical discharge capacity D2 of the second-stage gear train 37. Also, it is suppressed that the actual discharge capacity S2 of the second-stage gear train 37 is insufficient for the theoretical discharge capacity D3 of the third-stage gear train 38. Consequently, the DME is difficult to vaporize at the second and third gear trains 37 and 38, and 20 pressurization characteristics for the DME is ensured.

(1-2) When the DME vaporizes, cavitation occurs in the DME. As

cavitation bubbles burst, shock waves occur. Therefore, noise and vibration occur. However, due to suppression of the vaporization of the DME at the second and third gear trains 37 and 38, the noise and the vibration are suppressed.

5 (1-3) The shapes and the dimensions of the gear tooth 26a and 32a of the gears 26 and 32 are same as those of the gear tooth 27a and 33a of the gears 27 and 33 except for the facewidths  $h_1$  and  $h_2$ . Therefore, common portions between the gears 26, 27, 32 and 33 are larger in comparison with setting the tooth depth of the gears 27 and 33 of the second-stage gear train 37  
10 being shallower than that of the gears 26 and 32 of the first-stage gear train 36 so as to set the theoretical discharge capacity  $D_2$  of the second-stage gear train 37 being smaller than the theoretical discharge capacity  $D_1$  of the first-stage gear train 36. Consequently, it is easy to manufacture the gears 26, 27, 32 and 33 due to the common portions. Also, the relationship between the second and third gear  
15 trains 37 and 38 is same.

(1-4) In the present preferred embodiment, the theoretical discharge capacity  $D_2$  of the second-stage gear train 37 is equal to the actual discharge capacity  $S_1$  of the first-stage gear train 36. Also, the theoretical discharge capacity  $D_3$  of the third-stage gear train 38 is equal to the actual discharge capacity  $S_2$  of the second-stage gear train 37. Therefore, the leak rate of the DME at the second-stage gear train 37 is not relatively large. Also, the leak rate of  
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the DME at the third-stage gear train 38 is not relatively large. Meanwhile, the leakage of the DME at the second and third gear trains 37 and 38 causes power loss of the pump 1 that is converted into heat energy that raises the temperature of the DME. However, since the leak rate of the DME is not relatively large, the 5 power loss of the pump 1 is suppressed, and the DME does not become hot relatively.

In the present preferred embodiment, as mentioned above, the pump 1 copes with ensuring the pressurization characteristics of the DME and the 10 suppression of the noise and the vibration due to the suppression of the vaporization of the DME at the second and third gear trains 37 and 38. Also, the pump 1 copes with the suppression of the power loss of the pump 1 and the increase in the temperature of the DME due to the reduction of the leak rate of the DME. Consequently, the pump 1 has excellent performance.

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(1-5) The relief valve 46 is provided at the end portion of the first passage 43a on the side of the second passage 43b of the communication passage 43. When a required pressure of the pump 1 is varied and the DME is pressurized to the required pressure only by the first-stage gear train 36, a part of 20 the DME is discharged from the relief valve 46 into the discharge port 39a. Therefore, it is avoided that the DME is not sucked into the second-stage gear train 37 and leaks to the first-stage gear train 36 when the DME has a sufficiently

high pressure. Consequently, the power loss of the pump 1 can be suppressed.

Also, for example, when a clearance between the gears 26 and 32 of the first-stage gear train 36 and the connecting plate 21 is smaller than an assumed 5 value due to variation in design dimensions of the gears 26 and 32 of the first-stage gear train 36 and the connecting plate 21, only an unexpectedly small amount of the DME leaks at the first gear trains 36. Namely, the first-stage gear train 36 has a relatively high pressurization capacity. Therefore, even though the DME is pressurized to the required pressure at the first-stage gear train 36 under 10 the conditions, a part of the DME is discharged from the relief valve 46 into the discharge port 39a. As a result, workload of the second-stage gear train 37 is reduced. Also, since the relief valve is provided on the communication passage 47, the relationship between the second and third gear trains 37 and 38 is same.

15 (1-6) The O-rings 48a through 48f, the seal rings 49a through 49f and the seal rings 50a through 50f are arranged in the gear assembly 11 for ensuring the sealing between the pump chambers 36a through 38a and 36b through 38b and the interior of the casing 7. Therefore, the DME passing through the gear trains 36 through 38 is hard to leak out to the interior of the casing 7 and the 20 internal chambers 51 and 52.

(1-7) The driven shaft 29 is integrally formed with a single gear (the gear

32), and the other gears 33 and 34 are assembled to the driven shaft 29 so as to be rotatable relative to the driven shaft 29. Therefore, the gears 33 and 34 are rotated by the drive shaft 12. It is avoided that only a single gear out of the gears 32 through 34 receives load for the three gears 32 through 34. Consequently, 5 decrease in durability of the gears 32 through 34 can be suppressed.

For example, assuming that the driven shaft 29 is fixed to the gear assembly 11 so as to function as a fixed axle and rotatably supports the gears 32 through 34, the circumferential speed of the gears 32 through 34 relative to the 10 fixed axle is excessive. Therefore, in this case, it is necessary to interpose bearings between the gears 32 through 34 and the fixed axle so as to rotate the gears 32 through 34 without trouble. However, interposing the bearings makes the pump 1 large in size. Therefore, it is improper to function the driven shaft 29 as the fixed axle. It is preferable that the driven shaft 29 rotates at the 15 substantially same rotational speed as the gears 32 through 34.

In the present preferred embodiment, even though a phase of the driven shaft 29, which rotates integrally with the gear 32 engaged with the gear 26, is different from a phase of the gear 33 engaged with the gear 27 and a phase of the 20 gear 34 engaged with the gear 28, the driven shaft 29 rotates at the substantially same rotational speed as the gears 33 and 34. In the structure to rotate the driven shaft 29 at the substantially same rotational speed of the gears 33 and 34 without

interposing the bearings between the gears 33 and 34 and the driven shaft 29, the driven shaft 29 is rotated integrally with the single gear (the gear 32). Therefore, the decrease in the durability of the gears 32 through 34 is suppressed.

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(1-8) The driven shaft 29 is formed integrally with the single gear (the gear 32). For example, assuming that the gear 32 rotates integrally with the driven shaft 29 through a key, the bearing 31 needs to be arranged away from the key at a position where the bearing 31 does not interfere with the key (When a

10 gear is connected to a shaft through a key, the length of the key is generally larger than the facewidth of the gear.). In the present preferred embodiment, since the gear 32 is formed integrally with the driven shaft 29 without a key, the bearing 31 is arranged near the gear 32 in comparison to utilizing a key. Therefore, the driven shaft 29 is hard to bend.

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A radial load resulting from the rotational torque and a radial load resulting from the pressure in the pump chambers 36a through 38a act on the gears 26 through 28 at the side of the drive shaft 12 in a direction in which the above radial loads cancel each other. In contrast, the above radial loads act on 20 the gears 32 through 34 at the side of the driven shaft 29 in a direction in which the above radial loads overlap each other. Therefore, the radial load on the gears 32 through 34 at the side of the driven shaft 29 is larger than that on the gears 26

through 28 at the side of the drive shaft 12 (occasionally twice). In this situation, the driven shaft 29 receiving the radial load from the gears 32 through 34 bends easily.

5        Since the three gears 32 through 34 are formed or assembled to the driven shaft 29, a span between the bearings 30 and 31, that is, a bearing span is large in comparison to mounting a single gear or two gears on the driven shaft 29. Due to the large bearing span, the driven shaft 29 bends easily in this situation. Therefore, the structure to form the gear 32 integrally with the driven shaft 29 and  
10      to arrange the bearing 31 near the gear 32 is effective in preventing the driven shaft 29, which bends easily, from bending.

(1-9) Since the gear 32 having the largest facewidth among the gears 32 through 34 is formed integrally with the driven shaft 29, load applied from the  
15      drive shaft 12 to the gears 33 and 34 being rotatable relative to the driven shaft 29 can be dispersed in comparison to forming the gear 33 or 34 integrally with the driven shaft 29.

(1-10) The return passage is formed in the gear assembly 11 and  
20      interconnects the internal chamber 51 with the suction port 35a. The DME leaking out to the internal chamber 51 is returned to the suction port 35a through the return passage. Therefore, the pressure in the internal chamber 51 is

substantially equal to the suction pressure, and the thrust load on the drive shaft 12 is hard to generate.

(1-11) The port 56 is formed in the pipe connecting portion 54 so as to 5 interconnect the internal space of the motor 10 with the outside of the pump 1. The drain hole 57 is formed in the sidewall of the motor housing 10a so as to interconnect the internal space of the motor 10 with the space that is inside the casing 7. Therefore, the DME that evaporates and that is stored inside the casing 7 and the motor housing 10a is returned from the port 56 and the drain hole 57 10 into the tank 2 through the pipe 55. Consequently, insufficient cooling of the motor 10 caused due to congestion of the DME gas does not occur.

(1-12) The pump 1 includes the motor 10 and is a pump that seals a shaft therein. Therefore, an external drive source is unnecessary when the pump 15 1 is operated.

Next, the second preferred embodiment will be described according to FIG. 6. A pump 1 of the second preferred embodiment is a two-stage gear pump from which a shaft 12 protrudes. In the second preferred embodiment, only the 20 difference between the first and second preferred embodiment is described, and the identical or corresponding members are referred to the same reference numbers as those in the first preferred embodiment.

FIG. 6 is a cross-sectional view of the pump 1. A casing 7 of the present preferred embodiment is open to the lower side (the right side in FIG. 6). A cover 9 is secured to the lower end of a casing 7. The drive shaft 12 protrudes from the 5 upper side of the casing 7 to the outside of the casing 7, and the protrusion of the drive shaft 12 is connected to an external drive source (not shown). The pump 1 of the present preferred embodiment is the two-stage gear pump including a first-stage gear train 36 and a second-stage gear train 37. The first-stage gear train 36 is arranged on the upper side, and the second-stage gear train 37 is 10 arranged on the lower side.

A base block 16, a connecting plate 21, a side plate 20 and a connecting plate 19 are accommodated in the casing 7 so as to contact each other. In the present preferred embodiment, a gear 32 constituting the first-stage gear train 36 15 is formed separately from a driven shaft 29. A gear 33 constituting the second-stage gear train 37 as the highest-pressure stage gear train is formed integrally with the driven shaft 29. A discharge connecting portion 39 is provided on the cover 9, and a suction connecting portion 35 is not shown in the drawings.

20 In the present preferred embodiment, the same advantageous effects are obtained as mentioned in paragraphs (1-1) through (1-8) according to the first preferred embodiment. Also, following advantageous effects are obtained.

(2-1) The gear 33 constituting the highest-pressure stage gear train (the second-stage gear train 37) is formed integrally with the driven shaft 29. The gear 33 of the second-stage gear train 37 has a facewidth that is smaller than that of 5 the gear 32 constituting the first-stage gear train 36. Namely, the thickness of the gear 33 is smaller than that of the gear 32. As the thickness of a gear is small, the gear is easily inclined with respect to the driven shaft 29. However, since the gear 33 whose thickness is smaller than that of the gear 32 is formed integrally with the driven shaft 29, the above inclination does not occur. Therefore, in comparison to 10 forming the gear 32 with a large thickness integrally with the driven shaft 29, seizure and abrasion due to the inclination of the gear 32 are effectively avoided.

When the gears 26 and 27 are inclined with respect to the drive shaft 12, a component force of the radial load occurs in the gears 26 and 27 in the axial 15 direction. Similarly, when the gears 32 and 33 are inclined with respect to the driven shaft 29, a component force of the radial load occurs in the gears 32 and 33 in the axial direction. As mentioned above, the radial load at the side of the driven shaft 29 is larger than that at the side of the drive shaft 12. Therefore, the component force in the axial direction in the gears 32 and 33 at the side of the 20 driven shaft 29 is larger than that in the gears 26 and 27 at the side of the drive shaft 12, and the seizure and the abrasion due to the inclination of the gears 32 and 33 occurs more easily. In the present preferred embodiment, since the gear

33 having a facewidth that is smaller than that of the gear 32 at the side of the driven shaft 29 is formed integrally with the driven shaft 29, avoiding the inclination of the gear 33 with respect to the driven shaft 29 suppresses the component force in the axial direction. Consequently, in the pump 1, the seizure 5 and the abrasion due to the inclination of the gears 26 and 27 and 32 and 33 with respect to the drive shaft 12 and the driven shaft 29 are effectively avoided.

(2-2) Chamfered portions 32b are formed at connecting portions between the side surfaces and the inner circumferential surface in the gear 32 so 10 as to assemble the driven shaft 29 through the gear 32 easily. Also, chamfered portions are formed in the gears 26 and 27 and are not shown in the drawings. For example, it is assumed that the gear 32 is formed integrally with the driven shaft 29 and that the driven shaft 29 is inserted through the gear 33, chamfered portions with the same radii of curvature as the chamfered portion 32b are formed 15 in the gear 33. In the present preferred embodiment, a rate of the width of the chamfered portions 32b relative to the facewidth of the gear 32 in the inner circumferential surface of the gear 32 is small in comparison to the above-assumed case. Therefore, since the gear 32 is harder to incline than the gear 33 and the driven shaft 29 is inserted through the gear 32, the seizure and 20 the abrasion due to the inclination of the gear are effectively avoided. Also, increase in contact pressure of contacting portions (the inner circumferential surface of the gear 32 in the present preferred embodiment) in the gear 32 at the

side of the driven shaft 29 can be suppressed, and the durability of the gears 32 and 33 can be improved. The radial load at the side of the driven shaft 29 is larger than that on the side of the drive shaft 12 as mentioned above and acts on the contacting portion of the gear 32. Therefore, the increase in the contact pressure 5 of the contacting portion of the gear 32 is suppressed more effectively.

(2-3) The gear 33 constituting the second-stage gear train 37 as the highest-pressure stage gear train is formed integrally with the driven shaft 29. Therefore, the axis of the outer circumference of the gear 33 is offset relative to 10 the axes of the gear 29 and the gear assembly 11 in a relatively small degree, so a leak rate of the DME at the high-pressure stage gear train (the second-stage gear train 37) is relatively small. Since the discharge capacity of the high-pressure stage gear train is set to be smaller than that of the low-pressure stage gear train (the first-stage gear train 36), the leak rate of the DME affect 15 volume efficiency of the high-pressure stage gear train. However, the leak rate of the DME can be reduced, and high volume efficiency can be maintained.

(2-4) The pump 1 is a pump from which a shaft protrudes and that is driven by an external drive source. There is not a motor in the pump 1. Therefore, 20 the pump 1 can be small.

The preferred embodiment according to the present invention is not

limited to the above preferred embodiments and may be changed to following alternative embodiments.

In the first preferred embodiment, the gear 32 of the first-stage gear train 5 36 is formed integrally with the driven shaft 29. However, the gear 33 of the second-stage gear train 37 or the gear 34 of the third-stage gear train 38 may be formed integrally with the driven shaft 29. For example, in the first preferred embodiment, the gear 34 constituting the third-stage gear train 38 is formed integrally with the driven shaft 29, and the gears 32 and 34 as other gears are 10 assembled to the driven shaft 29 so as to be rotatable relative to the driven shaft 29. The pump 1 in the first preferred embodiment has three gear trains while the pump 1 in the second preferred embodiment has two gear trains. Therefore, in this case, the substantially same advantageous effects are obtained notably as 15 mentioned in the paragraphs (2-1) through (2-3) according to the second preferred embodiment.

For example, corresponding to the effect mentioned in paragraph (2-1), as the facewidth of the gear becomes small, the thickness of a gear is smaller, and the gear with the relatively small thickness is easy to incline with respect to 20 the driven shaft 29 (when the gear is assembled to the driven shaft 29 so as to be rotatable relative to the driven shaft 29.). The gear 34 of the third-stage gear train 38 most easily inclines with respect to the driven shaft 29. However, since the

gear 34 is formed integrally with the driven shaft 29, the seizure and the abrasion due to the inclination of the gear 34 with respect to the driven shaft 29 are effectively avoided. Consequently, regarding only obtaining the effect mentioned in paragraph (2-1) effectively, as the number of the gear trains of a pump 5 increases, the structure to form a gear constituting a highest-pressure stage gear train integrally with the driven shaft 29 is effective, especially for a gear pump having more than three gear trains.

In the second preferred embodiment, the gear 33 of the second-stage 10 gear train 37 is formed integrally with the driven shaft 29. However, the gear 32 of the first-stage gear train 36 may be formed integrally with the driven shaft 29. In this case, the substantially same advantageous effect is obtained as mentioned in paragraph (1-9) according to the first preferred embodiment.

15 In the first preferred embodiment, the relief valve (not shown) and the relief valve 46 as the valve means are arranged in the side plates 18 and 20 respectively. A relief valve may be arranged in one of the side plates 18 and 20. Also, the valve means is not an internal autonomous type as the relief valve 46, the valve means may be an external control type valve (e.g. an electromagnetic 20 valve) that opens and closes based on an output of a sensor that detects whether or not the pressure of the DME discharged into the communication passage 43 exceeds a predetermined value. The valve means may be removed from the

pump 1.

In the first preferred embodiment, the relief valve 46 in an open state is discharged the DME which has been pressurized to the required pressure into 5 the discharge port 39a. However, the DME is not discharged from the relief valve 46 into the discharge port 39a and may be discharged from the relief valve 46 by bypassing the high-pressure stage gear train. For example, the DME may be discharged from the relief valve 46 into the downstream passage at the third-stage gear train 38. Also, the DME is not discharged from the relief vale 46 10 into the interior of the pump 1 and may be discharged from the relief valve 46 into the discharge pipe 4.

In the first preferred embodiment, a return passage that interconnects the first chamber 51a with the third chamber 51c and a return passage that 15 interconnects the second chamber 51b with the third chamber 51c may be provided. The DME leaking out to the first and second chambers 51a and 51b is sent to the third chamber 51c through these return passages more smoothly than only through the slight clearance between the key 25 and the groove 12a. Sequentially, the DME is returned from the third chamber 51c to the suction port 20 35a through the already described return passage that interconnects the third chamber 51c with the suction port 35a.

Similarly, in the second preferred embodiment, a return passage that interconnects the first chamber 51a with the second chamber 51b may be provided. Therefore, the DME leaking out to the first chamber 51a is smoothly sent to the second chamber 51b through the return passage. Sequentially, the 5 DME is returned from the second chamber 51b to a suction port through a return passage that interconnects the second chamber 51b with the suction port.

In the second preferred embodiment, the pump 1 is installed in the vehicle in such a manner that the drive shaft 12 is arranged in a vertical direction. 10 When an engine is utilized as an external drive source, the pump 1 may be installed in the vehicle in such a manner that the drive shaft 12 is arranged in a horizontal direction.

The fluid that the multistage gear pump deals with is not the DME, and 15 the present invention may be applied to a multistage gear pump that deals with other fluids. The present invention is effective especially for a multistage gear pump that deals with fluid having one of low viscosity characteristics and easily vaporized characteristics.

20 The present invention is applied to the three-gear pump 1 in the first preferred embodiment and the two-gear pump 1 in the second preferred embodiment. However, the present invention is not limited to the above preferred

embodiments and may be applied to multistage gear pumps, such as a four-gear or five-gear pump, other than the two-gear and three-gear pumps.

In the relationship between the first and second gear trains 36 and 37,

5 the facewidth  $h_2$  of the second-stage gear train 37 is set to be smaller than the facewidth  $h_1$  of the first-stage gear train 36, thereby the discharge capacity  $D_2$  of the second-stage gear train 37 is set to be smaller than the discharge capacity  $D_1$  of the first-stage gear train 36. However, the tooth depth of the gears 27 and 33 constituting the second-stage gear train 37 may be set to be shallower than that  
10 of the gears 26 and 32 constituting the first-stage gear train 36, thereby the discharge capacity  $D_2$  of the second-stage gear train 37 is set to be smaller than the discharge capacity  $D_1$  of the first-stage gear train 36. Also, the same is true of the relationship between the second and third gear trains 37 and 38.

15 Although the O-rings 48a through 48f and the seal rings 49a through 49f and 50a through 50f are provided in the first preferred embodiment and the O-rings 48a through 48d, the seal rings 49a through 49d and 50a through 50d are provided in the second preferred embodiment, these O-rings and seal rings may be removed from the pump1.

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In the first and second preferred embodiments, the pump 1 is a pump that pressurizes and sends the DME to the engine 6 for the vehicle. However, for

example, the pump 1 may be a pump that pressurizes and sends operating oil to a machine tool.

In the first preferred embodiment, the gear 32 is formed integrally with 5 the driven shaft 29. However, the gear 32 may be rotatable integrally with the driven shaft 29 through a key. Similarly, although the gear 33 is formed integrally with the driven shaft 29 in the second preferred embodiment, the gear 33 may be rotatable integrally with the driven shaft 29 through a key. In these cases, the substantially same advantageous effect is obtained as mentioned in paragraph 10 (1-7) according to the first preferred embodiment.

Therefore, the present examples and embodiments are to be considered as illustrative and not restrictive, and the invention is not to be limited to the details given herein but may be modified within the scope of the appended 15 claims.